

Electro-Cardiography and its Importance in the Clinical Examination of Heart Affections.

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ELECTRO-CARDIOGRAPHY AND ITS IMPORTANCE IN THE CLINICAL EXAMINATION OF HEART AFFECTIONS.

PART I.

The Method Employed in Obtaining Electro-cardiograms.

THE electro-cardiographic method is one by means of which curves are obtained of electric changes which result in the body from the activity of the heart's muscle. The installation required for this work comprises a sensitive galvanometer and its accessory switchboards, and an arc light and camera.

The galvanometer used for the purpose is a peculiarly sensitive one;* it is composed of a heavy electro-magnet, the poles of which are closely approximated. Between the poles, and lying in the magnetic field, an extremely light conducting fibre is stretched, which consists of a finely drawn platinum or silvered quartz thread. It is this thread which acts as the recorder. If a small current is passed through it while it lies in the magnetic field, it becomes deflected and takes up a new position, a position which is governed by the direction in which the current flows through it, by the strength of the current and the sensitivity of the instrument. The sensitivity of any given instrument is controlled by the magnification of the string and its tension. The magnification is arranged by means of a microscope driven through one pole of the magnet; the other pole is bored to contain a condenser. A beam of light, falling through the condenser and concentrated upon the string, projects the magnified image of the string upon the screen of the camera. The magnification usually adopted is approximately 600 diameters; it is kept constant. The sensitivity of the instrument, from time to time, consequently depends upon the tension of the conducting fibre, and this is arranged to give a standard deflection for a given electric change. The standard adopted by all who practise human electro-cardiography

* Such a galvanometer is supplied by the Cambridge Scientific Instrument Company.

is the same. When the ends of the string are connected to form a circuit and an electro-motive force of 1000^1 volt is introduced into this circuit, the deflection of the projected string image amounts to 1 cm. The deflection of the string is in exact proportion to the strength of current which passes through it. Thus, if 1000^2 volt are introduced into the circuit a deflection of 2 cm. results. If, instead of introducing an electro-motive force from a battery, the human body is connected to the string by suitable means, the string moves in response to changes of potential produced in the body as a result of the heart beat; and the movement of the string's shadow in response to these natural cardiac electric effects is of sufficient amplitude to permit it to be photographed upon a moving plate surface. The photographic apparatus consists of a moving plate camera, the string is vertical, and its shadow falls upon the vertical screen on the front of the camera. Its movements are from side to side across the front of the camera, and across a horizontal slit in the front, behind which the plate travels. As the plate travels the shadow of the moving string protects the sensitive surface of the plate from the light, and when the plate is developed the record of the movements remains upon the plate as a white band upon a black background. Prints from this plate, such as are here reproduced, show a black band upon a light background. The plate falls on its end in the camera, the print is turned upon its side for reproduction. As the plate moves the light is also prevented from falling upon its surface by a screen on which fine lines are ruled at intervals of 1 mm. These lines are horizontal in the records and serve to facilitate measurement; each is equivalent to 1000^1 volt (see Fig. 1). The light is also shaded by a vibrating time marker, which records thirtieths of a second upon the plate.

The object of standardizing the movements of the string is as follows: If allowance is made for the whole resistance of the circuit, consisting of string, the human body, and the connecting wires, the development of a given potential difference at the points of the body from which the current is led off gives rise to a deflection of the string of a definite value, which may be compared with the deflection resulting from the employment of a potential difference of known amount. The same heart will give electro-cardiograms similar in outline and magnitude from time to time; and it will yield similar records with different instruments, providing that the body is connected to the galvanometer in the same manner. Thus an absolute comparison may be made of curves taken from the same subject from time to time; and to a lesser extent of curves from patient to patient. The electro-cardiograms from no two subjects are the same; they differ slightly both qualitatively and quantitatively. Such being the case, and the type of electro-cardiogram remaining constant in any healthy person for long periods, the identification of any individual from his electro-cardiograms is a matter of no great difficulty.

It is customary in leading off the heart currents from the patient to adopt three leads: *I*, horizontal, from the right arm to the left arm; *II*, oblique, from the right arm to the left leg; and *III*, vertical, from the left arm to the left leg. I shall speak of these leads hereafter simply as leads *I*, *II*, and *III*. In the illustrations these leads are marked in the upper left-hand corner of each strip of curve. The limbs are connected to the instrument by plunging them in baths of salt water, the baths being themselves connected to the string. As soon as the string is placed in circuit with the body in this fashion its movements commence, and may be recorded when appropriate adjustments have been made. And within certain limits it is a matter of indifference how far away the patient sits from the instrument; the wires which carry the current from his body may be several miles in length. Providing that they are properly protected, and that their own resistance is allowed for, the records remain unchanged.

The Form of the Human Electro-cardiogram.

The form of the human electro-cardiogram varies according to the points of the body from which the current is derived. As I have said, three leads are commonly employed. For the time being let us consider a single one, the most serviceable—namely, that which is

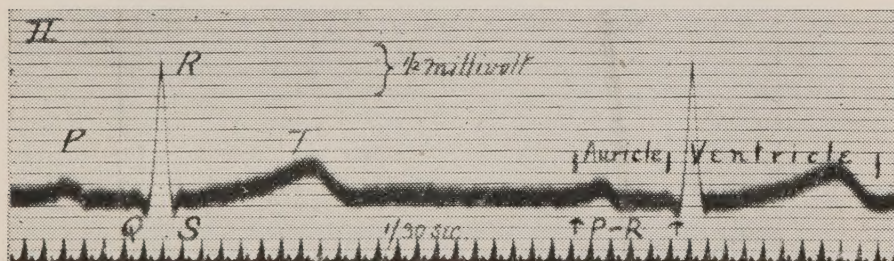


Fig. 1.—A normal electro-cardiogram from lead *II* (R. A. to L. L.). It shows two heart cycles; each consists of *P*, the auricular summit, and the deflections *Q*, *R*, *S*, and *T*, the ventricular deflections. The line is straight and horizontal during diastole. The normal electro-cardiogram is inscribed only when the heart-beat starts at the normal site, traverses the auricle and the auriculo-ventricular bundle, and is distributed to the ventricle and through its substance by the usual and recognized channels. The time marker of this and subsequent figures is in $\frac{1}{30}$ seconds, and is seen along the bottom edge of the curve. The fine horizontal lines at millimetre distances facilitate measurement. Each centimetre of a heart deflection is equivalent to $\frac{1}{1000}$ volt.

in the nearest line to that of the heart's axis, the right arm to the left leg (lead *II*). Such an electro-cardiogram from a normal subject usually consists of five separate phases, and these are called *P*, *Q*, *R*, *S*, and *T* (see Fig. 1). It is necessary to examine but briefly the meaning of these phases. *P*, the first phase, is due to the simultaneous contraction of the two auricles. *Q*, *R*, *S* and *T* (of which *R* and *T* are the most prominent) are the result of simultaneous contraction of the two ventricles. We will be content with this statement for the time being, without further attempting the explanation of the various summits

and depressions of the curves. We have in electro-cardiography the only certain method of obtaining separate records of the movements of the upper and lower chambers of the human heart; and, as we shall see, these records may tell us a great deal as to how the separate chambers are fulfilling their functions.

The curves from the other leads, *I* and *III*, are not altogether dissimilar to those derived from lead *II*; though they never duplicate it (Fig. 2). The main summits, *P*, *R* and *T* are still seen, and *Q* and *S* also appear in varying degree. We shall understand the special values of these leads almost immediately.

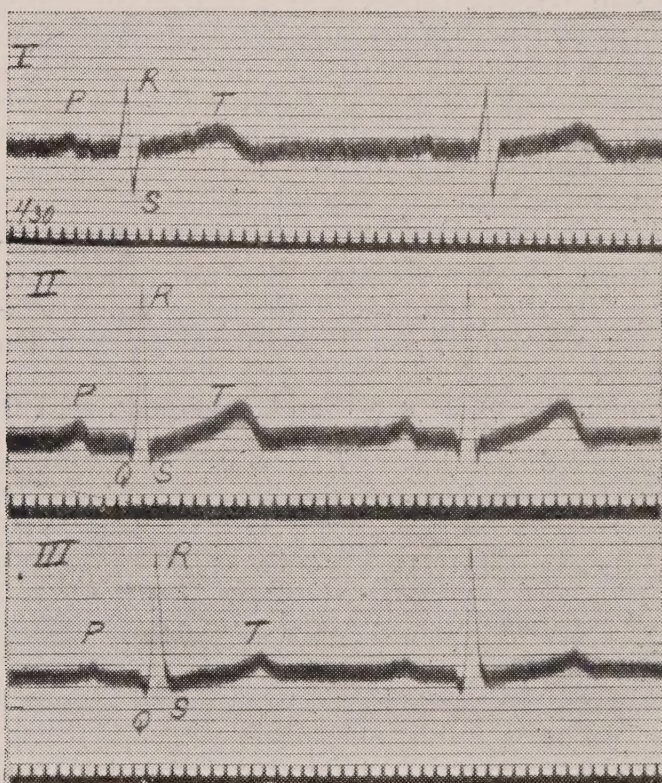


Fig. 2.—Three normal electro-cardiograms from the same subject as Fig. 1. They were taken from lead *I* (R.A. to L.A.) lead *II* (R.A. to L.L.) and lead *III* (L.A. to L.L). Each shows *P*, the auricular representative, and *R* and *T*, ventricular representatives, *Q* and *S* are present in varying degrees. Note the conspicuous *R* summit in each lead and the variations in height of the several deflections from one lead to another. The heights of the peaks in the second lead are similar to those found in Fig. 1. The two figures were taken from the same subject and same lead, but on different days.

The Direction of Lead.

In speaking of the value of electro-cardiograms in the diagnosis and management of cardiac affections, we may choose certain illustrations; in selecting them at the present time, I shall not only choose them as illustrations of the method, but I shall also specially select those which have an immediate and unquestionable practical value. And the first illustration is a simple one; it shows that the direction of lead is all-important, and demonstrates

the particular value of a given lead under certain circumstances. Supposing that in a normal subject we lead off from right arm to left arm (lead *I*). The curve which results will be similar to that shown in Fig. 3A. But supposing that we lead off in the reverse direction—that is, from left arm to right arm, what will result? We change the direction in which the same currents flow through the string. Its movements will consequently be of similar amplitude and similar form, but *opposite in direction*. The two pictures will differ from each other in one respect, and one only. The second will be upside down (Fig. 3B). The practical value of this fact is seen when we turn our attention to transposition of the heart. Regarded from the point of view of the heart, the right arm in the subject of heart transposition is where the left should be; the left is where the right should be. Consequently an electro-cardiogram from lead *I* in a subject who has a transposed heart will be similar to an electro-cardiogram from a normal subject from lead *I*, but

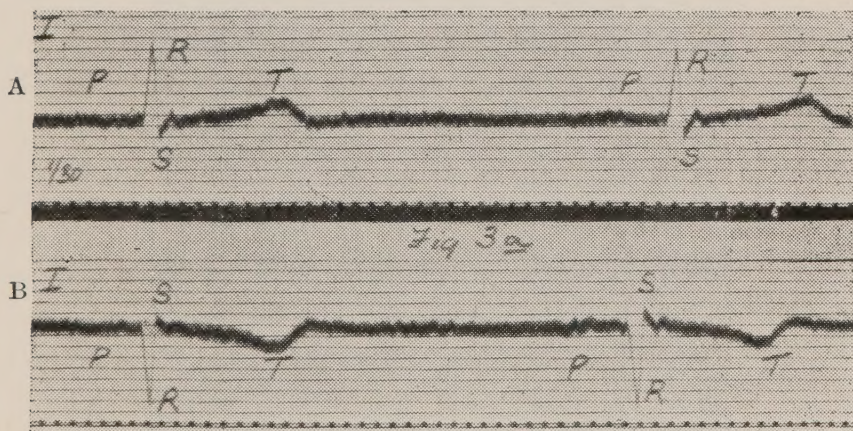


Fig. 3A.—A normal electro-cardiogram from lead *I* (R.A. to L.A.), the only symmetrical lead. *P* is small, *R* and *T* are conspicuous. The deflections are in the usual directions.

Fig. 3B.—An electro-cardiogram from the same subject. The lead was from L.A. to R.A. (lead *I* reversed). The electro-cardiogram is upside down. Such curves are obtained from lead *I* (R.A. to L.A.) when the heart is transposed, and in this condition alone.

it will be inverted. In other words, all the summits and depressions of the curve will be upside down. This reversal of the picture applies to lead *I* alone, for it is the *only symmetrical lead*. Now transposition of the heart is a rare condition, but it not infrequently happens that the human heart is displaced, and it is also by no means uncommon that the cause of its displacement cannot be found; in all such instances the question of transposition may arise. The electro-cardiographic method returns a perfectly clear answer to the question, Are we dealing with a transposed heart? Displacement of the heart certainly alters the form of the electro-cardiogram, and deforms the normal curve in definite and known ways, which I do not propose to consider at the present time.

It is sufficient to know that displacement never yields the completely inverted electro-cardiogram; transposition always does. The electro-cardiographic test is the most certain means of differentiating the two conditions.

Enlargement of the Heart.

The chief object of recording the electro-cardiographic curves of one subject by means of three leads is the attempt to differentiate between right-sided and left-sided hypertrophy of the heart. If curves are taken from normal subjects, it is the rule to find that the summit *R* is a *prominent* upward deflection in all leads (see Fig. 2); *S*, if present, is a *small* downward deflection. If, on the other hand, the same leads are adopted in a case in which there is clear evidence of right-sided hypertrophy, certain changes in the shape of the curves are discovered (Fig. 4). In lead *I*, *R* is *small* or absent and *S* is deep. In lead *III*, *S* is small or absent, and *R* is relatively high. If the curves (Fig. 4) are examined it will be seen that the prominent

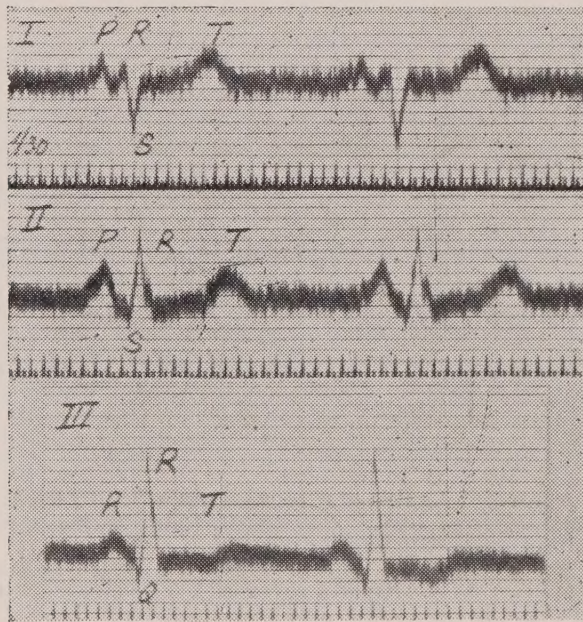


Fig. 4.—The electro-cardiograms (leads *I*, *II*, and *III*) from a case of mitral stenosis. The figure demonstrates the exaggerated *P* summit in lead *II*, which is so frequently found when there is auricular hypertrophy; it shows the modifications of the ventricular deflections which consort so commonly with right ventricular hypertrophy; *R* is almost absent in lead *I*, while *S* is deep; *R* is tallest in lead *III*, while *S* is absent.

deflections in question, *R* in lead *III*, and *S* in lead *I*, point *towards each other*; the deep *S* of lead *I* and the tall *R* of lead *III* are directed upwards and downwards towards the centre of the figure. If the same three leads are adopted in a frank instance of left-sided hypertrophy the reverse picture may be anticipated (Fig. 5): *R* is large in lead *I*, *S* is small or absent; *R* is small or absent in lead *III*, *S* is large. The exaggerations of the peaks *R* in lead *I* and *S* in lead *III* are *away from each other*.

It is in the new-born child, in pulmonary stenosis, and in mitral stenosis that the first grouping (Fig. 4) is so frequently encountered; it is in aortic and renal disease that the last grouping (Fig. 5) occurs most commonly.

The difficulty of differentiating right as opposed to left-sided hypertrophy in any thing but the frankest of cases by ordinary physical signs is well known; often—indeed, frequently—it is impossible. The electro-cardiographic curves are not the least valuable indications which we possess to-day; and they may be of special service in several groups of cases. Apart from the intrinsic value of the differentiation, it is of special importance to ascertain the relative degree of right and left-sided hypertrophy in cases where there are murmurs at the base of the heart. It may

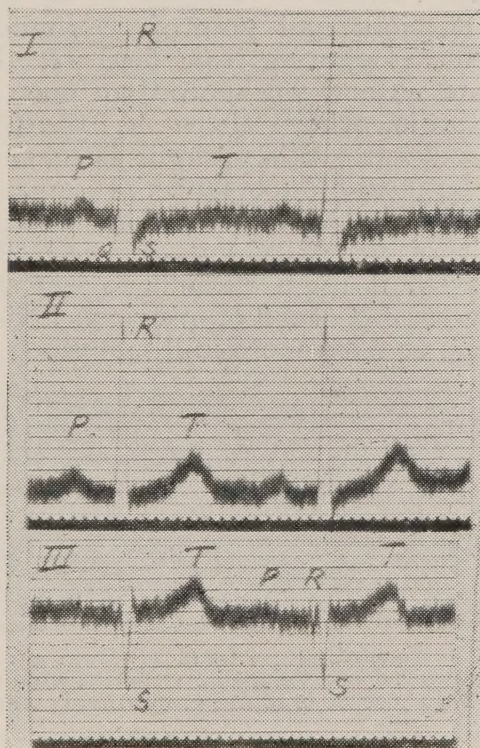


Fig. 5.—Three electro-cardiograms (leads I, II, and III) from a case of aortic disease and enlargement of the heart. The figure shows the modification of the deflections so frequently found where there is left-sided hypertrophy. *R* is tallest in lead I and *S* is short. *S* is deep in lead III, while *R* is almost absent. The arrangement is the reverse of that seen in Fig. 4.

be that, with the presence of a diastolic murmur in the aortic area in a patient who has a rheumatic history, a presystolic sound or actual murmur is heard at the apex; and the question arises as to whether stenosis of the mitral valve is present, or whether the apical murmur is of the kind described by Flint and attributable to the aortic lesion also. If it can be decided that left-sided hypertrophy predominates, such a fact emphasizes the aortic lesion; if right-sided hypertrophy predominates, the presystolic murmur may be attributed to constriction at the mitral orifice. Confusion not uncommonly arises in young subjects between the diagnosis of pulmonary and

aortic lesions. The two valves which guard the respective arteries are near to each other; lesions of the former are accompanied by right-sided, and lesions of the latter by left-sided, hypertrophy. Again, how frequently one meets with cardiac patients—patients who have mitral stenosis, but in whom the presystolic murmur is absent; in such cases electro-cardiographic examination is often of great value, for it indicates that the muscle of the right side predominates. And this is especially the case, as will appear hereafter, when the heart's action is irregular.

PART II.

The Auricular Summit in Mitral Stenosis.

The summit *P*, which corresponds to the contraction of the auricles, is small and pointed or rounded in most normal electro-cardiograms from lead *II*. As a rule its height does not extend for more than one scale division. In mitral stenosis, where there is hypertrophy of the auricular musculature, this summit is considerably modified and is of diagnostic importance. It is generally broad, flat-topped, and bifurcates in its centre (the last-named feature is not of necessity pathological), its height is greatly increased, it often extends to two scale divisions (Fig. 6; see also Fig. 4 *II* of previous article) and may amount to three or even more millimetres.

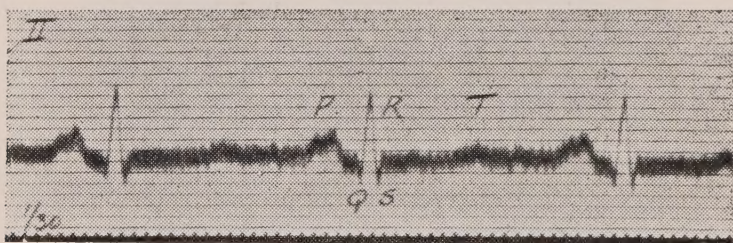


Fig. 6.—An electro-cardiogram (lead *II*) from a case of mitral stenosis. It shows the exaggerated *P* summit, which is broad, flat and divided. This picture is common in mitral stenosis.

The sign is of chief clinical value in cases of mitral stenosis in which murmurs are absent or obscure, and in such cases galvanometric examination may decide an otherwise doubtful diagnosis.

"As-Vs" Interval.

The normal heart beat consists of a sequence of chamber contractions. The contraction begins in the auricle and having passed through it is transmitted to the ventricle through the specialized tract of tissue known as the auriculo-ventricular bundle; the ventricle having received both its charge of blood and impulse from the auricle, contracts. There is an appreciable delay between the contractions of auricle and ventricle in a normally acting heart, and the length of interval between the onsets of the contractions is taken as a measure of the functional efficiency of the bundle in question. This interval is readily ascertained in human electro-cardiograms. It is

represented by the distance from the commencement of the auricular summit *P* to the commencement of the ventricular summit *R*. In normal electro-cardiograms this *P-R* interval measures between 0.12 and 0.18 second.

But in pathological hearts the interval is often greatly increased; it often reaches 0.3 second (Fig. 7) and may extend on occasion to as much as 0.4 second. Prolongation of this interval is the first of a series of extremely interesting and important phenomena which are spoken of collectively as "heart-block," phenomena which are due to impairment of the tissue functions in the tract which conveys the contraction impulse to the ventricle. The impairment of bundle function produces delay or hesitancy of the impulse transmission, which can be discovered with certainty only in graphic records taken from the heart. It leads to no disturbance of the beats which is evident during ordinary clinical examination. Yet we cannot afford to neglect it. It is a frequent sign in heart disease; it may be a forerunner of grave disturbances of the heart's

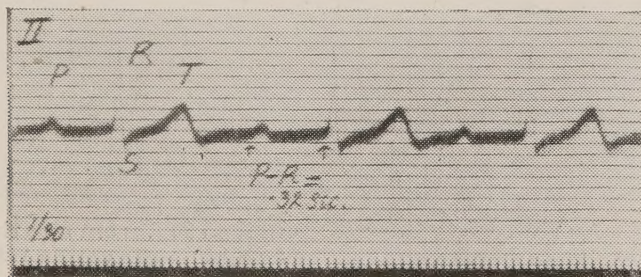


Fig. 7.—An electro-cardiogram from a case of subacute infection of the bladder. The *P-R* interval is prolonged; there is hesitancy in the transmission of the impulse from auricle to ventricle, and consequently evidence of damage of the tissues joining the auricle and ventricle. The disturbance in conduction was the sole sign of myocardial disturbance in this patient at the time when the curve was taken.

mechanism, which will be spoken of later; it is in itself always serious. The length of the *P-R* interval is one of the important prognostic signs in mitral stenosis, for such hearts when regularly exhibiting prolongation of the interval are hard hit, and the damage is not necessarily confined to the auriculo-ventricular bundle, but is usually disseminated throughout the heart muscle. A prolongation of the *P-R* interval is not at all an infrequent sign during the course of acute infections, especially those of rheumatic type. It may be that a patient who exhibits some slight enlargement of the heart, or in whom a systolic murmur of rheumatic origin is present, develops a sore throat or slight febrile attack or soreness of the joints. At the same time prolongation of the interval may be noticed. It may even occur apart from other manifestations of infection. Whenever it develops it is a sign of considerable consequence, for it indicates involvement of the heart muscle. Clinical medicine has recognized lesions of the heart valves for many years; it has looked almost in vain for signs of early muscle damage. Advanced rheumatic disease of the heart has essentially a long history behind

it; it probably results from repeated infection and repeated slight damage of the valves and muscle. Transitory prolongation of the interval between auricular and ventricular contractions is one of the very few signs which we possess of these invasions. The greater part of the ventricular musculature may be spoken of as silent, in the same sense that large areas of the cerebral substance are termed silent. The auriculo-ventricular bundle, like the pyramidal tracts of the spinal cord, gives, when damaged, early indications of such damage, though the lesion may not be, and usually is not, confined to it. The electro-cardiogram thus serves an extremely useful purpose, for it not only gives us an accurate index of the manner in which the functions of the auriculo-ventricular bundle are fulfilled, but it also throws light upon the condition of the myocardium as a whole. A single manifestation of bundle deficiency is spoken of at the present time: others will be noted at a later stage.

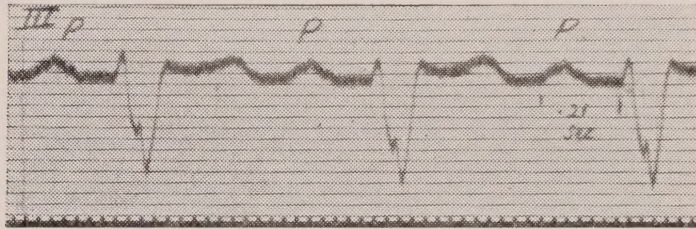


Fig. 8.—An electro-cardiogram from lead *III*, from a patient who had heart enlargement. The auricles (*P*) are beating regularly; each auricular contraction is followed by a ventricular beat of anomalous form, at an increased interval. The *As-Vs* interval is increased to 0.21 second, indicating damage of the main bundle. The shape of the ventricular portions of the curve indicates that the right bundle branch has also been damaged and no longer conducts. The impulse from the auricle is consequently conducted to the ventricle along the left strand only. As a result the contraction reaches the ventricles and starts the contraction in them in an abnormal manner. The normal electro-cardiogram results when the contraction spreads from both sides almost simultaneously. This form of abnormal curve results, as shown by experiment, when the contraction spreads to both ventricles from the left side.

Lesions of the Bundle Branches.

The auriculo-ventricular bundle divides into two large branches near the ventricular septum and these run and arborize under the endocardium before joining the muscle of the ventricle. Just as lesions of the main stem of the bundle give rise to electro-cardiographic signs, so do lesions of its branches; and a number of such lesions may be recognized to-day, and their significance may be appreciated. A lesion of a bundle branch results, not in a prolongation of the conduction interval, but in profound modification of the manner in which the auricular impulse is distributed to the ventricle through the conducting system as a whole; the result is a profound modification of the type of electric curve which represents ventricular contraction, for the type of electric curve is chiefly dependent upon the point or points at which contraction starts in the muscle from which it is recorded.

types of curve which are found in mitral stenosis. It will suffice if I give a single additional illustration. In my first article I spoke of standardization of curves, and it is known that the height of the greatest peak in normal curves rarely exceeds 10 or 15 scale divisions. In congenital heart disease values of 25 or even 30 scale

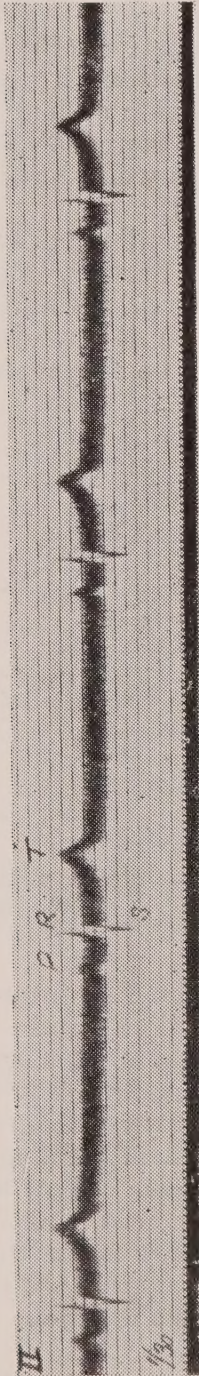


Fig. 10a.—An electro-cardiogram from an athlete who exhibited bradycardia. The pulse and ventricular rate were 35 per minute. In the figure each cycle consists of the usual auricular and ventricular summits. The whole heart is shown to have been involved in the slowing.

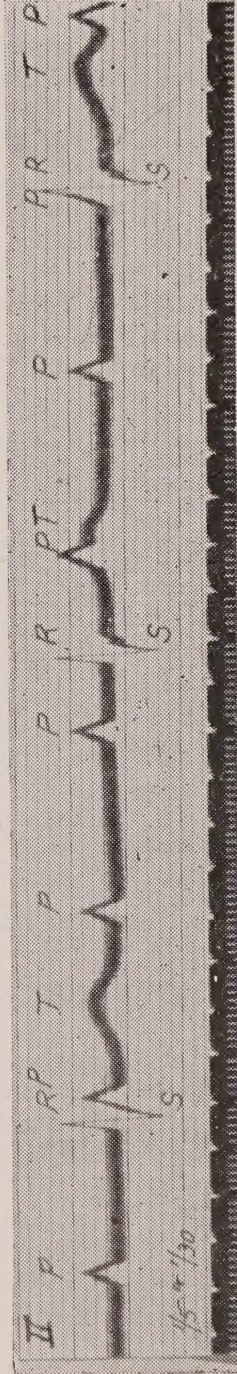


Fig. 10b.—An electro-cardiogram from a patient who exhibited bradycardia of a different form. The pulse and ventricular rate were 30 per minute. The ventricular beats are seen in the curve; they are represented by deflections *R*, *S* and *T*, and are placed regularly. In addition, a number of auricular summits, *P*, are seen; they are placed quite regularly in the curve, but fall with varying relations to the ventricular curves. There are two independent rhythms; one, auricular, at the rate of 77; and the other, ventricular, at a rate of 30. The condition is spoken of as complete heart-block, and results from discontinuity of the auriculo-ventricular bundle.

divisions are not at all uncommon (Fig. 9) and sometimes values of 45 and more are found; such exaggerations are consequently of value in the recognition of these malformations.

*The Nature of Bradycardia as Portrayed by
Electro-cardiograms.*

When the *pulse-rate* is slow its slowness may be due, as is well known, to one of two causes. The ventricular rate may be retarded, or a number of the heart-beats may fail to reach the wrist. The last condition will be dealt with more fully at a later stage. The first, or "bradycardia" (a term generally used for slow action of the ventricle), is not, as was formerly thought, a simple condition. It may result from slow action of the heart as a whole, or from deficiency in the conduction of impulses as they travel through the heart from its upper to its lower chambers; and the two states must be carefully distinguished, for, as the life-histories of such hearts are different, so the prognosis and treatment are different. Electro-cardiograms readily distinguish between them.

The ventricular beats are seen in both, and they occur at similar and widely spaced intervals (Figs. 10*a* and 10*b*); but while in slowing of the whole heart a single auricular summit *P* precedes each ventricular contraction (Fig. 10*a*), where there is deficient conduction many such auricular summits are found, and they may fall, as in Fig. 10*b*, with varying relations to ventricular systoles. Two rhythms are established, the one auricular, the other ventricular; each is regular and independent of the other. This is the condition, spoken of as complete heart-block or complete dissociation, which is so often associated with attacks of loss of consciousness (Stokes-Adams syndrome). It is the last stage in the series of phenomena which result from damage to the auriculo-ventricular bundle, and results from grave impairment of this tract, so that no auricular impulses are conducted to the ventricle. If a patient has a ventricular rate of 30, 40, or 50, we are no longer satisfied in describing his symptom as "bradycardia"; a further analysis of the nature of the heart's mechanism, to determine the cause of the slow ventricular action, is essential before we can foretell the future history of the heart or suggest those measures which are best calculated to prolong its action.

*The Nature of Regular Tachycardia as Portrayed by
Electro-cardiograms.*

When the pulse and ventricular beats are regular and rapid, the acceleration may often be ascribed to fever, infection, poisoning, or some specific disease such as exophthalmic goitre. But there is a large class of patients in which the causation of tachycardia is by no means easy to determine by ordinary clinical means.

A number of patients, who are in reality sufferers from paroxysmal tachycardia, come under observation during the attacks (which may have a duration of a few hours or many months) and the true condition readily escapes detection; a number have *persistent* tachycardia of cardiac origin. The tachycardia, whether paroxysmal or

persistent, may be from 120 to 300 in rate. Electro-cardiography is especially valuable in such cases. When the heart is accelerated as a result of fever, poisoning, or exertion, the general form of the electro-cardiogram is retained. The summits corresponding to the auricular and ventricular contractions are clearly visible (Fig. 11) and are of normal outline. But in the special group of heart cases to which I refer such is not the case. It is customary to find either that the auricular summit has vanished or is obscure (first half of Fig. 14) or that it is inverted (Fig. 12).

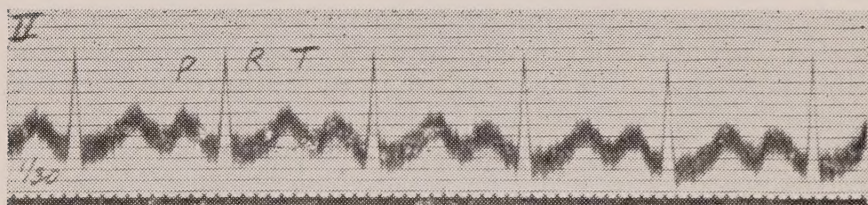


Fig. 11.—An electro-cardiogram showing tachycardia in exophthalmic goitre. The rate is 150 per minute. In this instance the heart beats have started in the usual situation, the junction of the superior vena cava and auricle, as evidenced by the normal shape of *P*. The ventricle (*R, T*) has responded to each auricular beat. It is an example of a tachycardia which has arisen as a result of altered innervation or altered nutrition of the normal pace-maker.

These signs are invaluable, for they immediately acquaint us with a pathological fact which has only recently been discovered, namely, that the site of origin of the heart-beat may suffer displacement.* The normal heart-beat is now known to start in the region of the union of the superior vena cava and the right auricle. The abnormal or dislocated rhythms

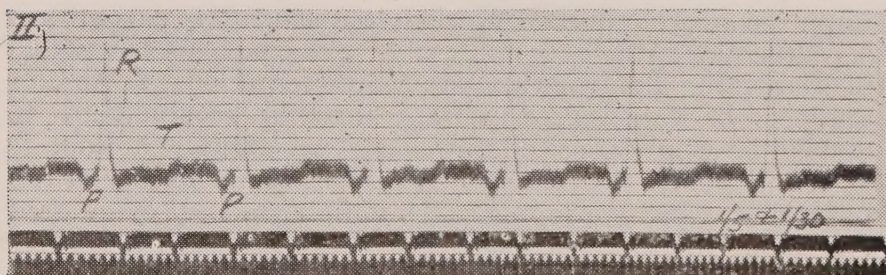


Fig. 12.—An electro-cardiogram taken during a paroxysm of tachycardia. The rate is 132 per minute. The tachycardia has arisen from an abnormal auricular focus, which is known from the inversion of *P*. Each auricular contraction gives rise to a ventricular response (*R, T*).

may start at several other points, for example, near the coronary sinus. The absence of auricular summit or its inversion is a sign of the awakening of new impulses in a portion of the heart muscle at some distance from the normal starting point, and the tachycardias with which such signs are associated are known to belong to a specific and essentially cardiac group; they run their own special courses. Such tachycardias react to rest, drugs, and other

* That they signify displacement of the "pace-maker" is known from experimental observations.

agencies in a manner quite their own. Thus, where tachycardia exists, electro-cardiography is not only a valuable aid in diagnosis, but is also most helpful in guiding treatment.

Amongst the tachycardias of elderly subjects one form exists which is of special interest. The pulse-rate and the rate of beat at the apex may be 120 or perhaps 150. The rate persists and the cause is not determined. Electro-cardiography reveals the unexpected fact that the true rate of heart-beat is much greater, for while the ventricle beats at 120 or 150 the auricular rate is 240 or 300 (Fig. 13). The type is of importance not only because it has its own peculiar prognostic features, but also because it reacts in a special manner to drugs of the digitalis group. Often, by suitable treatment, the normal heart action may be restored. These cases are not uncommon. I have seen an instance of a similar kind in which, while the auricles beat at 300 per minute, the ventricles beat at 75, or exactly a quarter of the auricular rate; the rapidity of the auricular action could not be determined in this patient who had a normal pulse-rate by any other means than electro-cardiography.

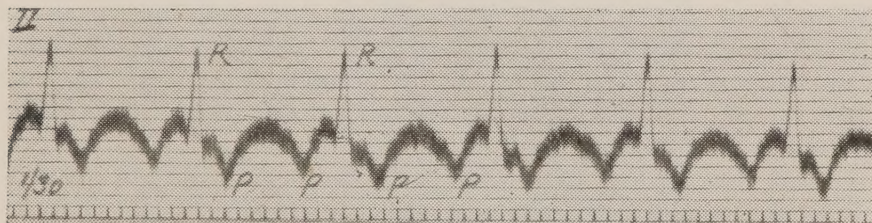


Fig. 13.—An electro-cardiogram from an elderly patient with persistent tachycardia. The ventricle (*R*) is beating at 159 per minute. Before each ventricular summit *R* is an inverted auricular deflection *P*; another *P* deflection is seen in the usual position of *T*, the latter being inconspicuous. The series of *P* deflections occur at regular intervals throughout the curve. The rate is 318 per minute, or exactly twice that of the ventricle. The auricular beats have arisen in an abnormal focus, as evidenced by the form (inverted) of their electric curves.

One of the great lessons which graphic records have taught is the fallacy of judging heart-rate by pulse-rate, or even by the rate of beating of the heart's apex. If a man's pulse is said to beat at 100 per minute, the statement awakens an impression which is governed largely by experience of the reaction of heart-rate to fever, infections and other common causes of altered rate. Judged from this point of view, conclusions drawn from an observation of the pulse-rate are only valid if the pulse is a true guide to the rate at which the heart beats are generated at their normal starting point. It is obvious that conceptions based upon actual pulse-rate are erroneous when apex and pulse fail to agree; the rate of one may be double the other. But the rate of apex beat is often equally deceptive. When we wish to arrive at a conception of actual heart-rate, and of its increase or decrease in response to chemical or nervous influences, it is important that our

thoughts should carry us, not to the ventricle, but to the actual starting point of the rhythm. Auricular and ventricular rates may not correspond. And it is equally important, as shown by actual practice, that we should fully avail ourselves of our means of determining the

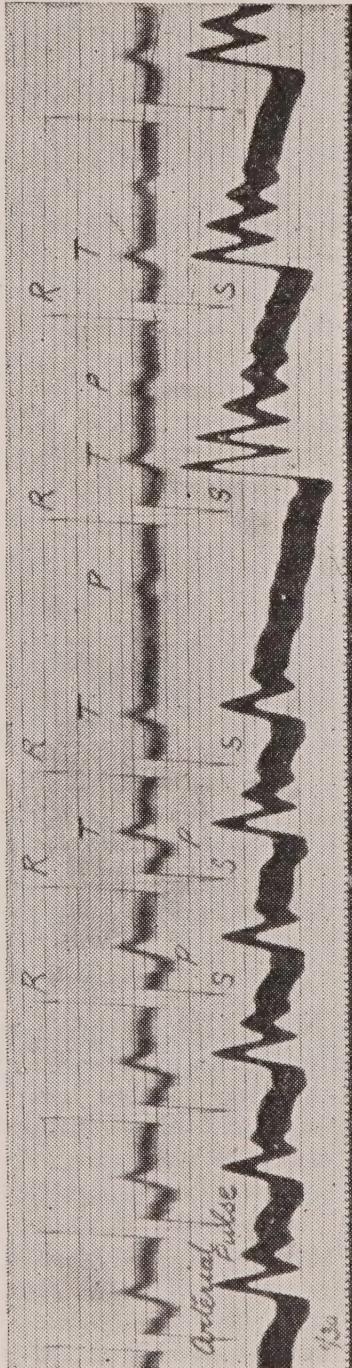


Fig. 14.—An electro-cardiogram and brachial pulse curve from a patient who was the subject of paroxysms of tachycardia. The figure shows the end of a paroxysm; the tachycardia (rate 127) terminates abruptly, and after a pause the normal rhythm is resumed (rate 72). The normal rhythm to the right is represented by the auricular summit *P* and ventricular deflections *R*, *S* and *T*. The tachycardia is represented to the left by ventricular beats, *R*, *S* and *T*, of the same form; this shows that the tachycardia has arisen above the ventricle, for the impulses have coursed along the normal ventricular channels. The auricular beats are represented obscurely. The *v* are inverted, and fall upon the *T* deflections, slightly deforming all but the last beat of the paroxysm. The paroxysm has arisen in an abnormal auricular focus.

actual site of origin of the heart beats in the individual case; for if, as often happens, the seat of impulse formation has been displaced, none of those rules which customarily guide us in judging of its rate and its reactions are longer applicable. I may illustrate these contentions by referring to the special type of tachycardia exhibited

by elderly people. The ventricular rate is usually but half the full and true heart-rate. Again, the normal heart-rate is influenced in many ways, notably by posture. The rate falls when the subject passes from the upright to the supine posture. In the tachycardia of which I speak that is not the case; the rate is maintained in all positions; and if there is a fall of auricular rate in such a subject, the fall is not gradual, as in that of the accelerated normal rhythm; it is abrupt, as is the fall in all tachycardias which have abnormal starting points; the change occurs with one heart-beat; the fall comes when the new rhythm vanishes and the old rhythm is resumed (Fig. 14).

The necessity for a clear analysis of the heart action may be further illustrated by the same group of cases. We are dealing perhaps with a case in which auricle and ventricle are beating regularly at 240 and 120 respectively. Alternate auricular impulses alone reach the ventricle and stimulate its contraction. Suppose that this patient is placed upon digitalis. When the drug is administered the pulse is 120 and regular. Digitalis, by increasing the grade of block, may reduce this pulse-rate to 60; under these circumstances it does not reduce the auricular rate, which remains at 240; but it further impedes transmission, so that whereas one impulse in two originally awakened ventricular response, after its administration one impulse in four finds a passage. Thus, though the pulse-rate has reached normal limits, the true heart-rate is as it was before. But before the ratio 240 : 60 (or 4 : 1) is established, the heart passes through a transitional period, during which cycles of 2 : 1 and 4 : 1 ratios are mixed, and the pulse therefore becomes very irregular. *The development of this irregularity*, when the pulse-rate falls from 120 to 100 or 80 and while the patient is upon digitalis, *is a favourable sign*, for it is an indication that the heart is reacting to the drug, and a further fall of pulse-rate and a return to the regular state may be predicted with some confidence if the drug is continued or its dosage increased.

Paradoxical as this conclusion may seem at first sight, and untenable as it would appear were the analysis of irregularities impossible, it is none the less true. It serves to illustrate that conclusions which apply to one form of heart action do not apply to another, and emphasizes the necessity that the mechanism of the beat should receive thorough investigation.

PART III.

The Analysis of Cardiac Irregularities.

In the preceding parts I have dealt almost exclusively with illustrations of the value of electro-cardiography in the examination of hearts which beat regularly. In the present part I propose to describe and illustrate the more important forms of heart irregularity as they are portrayed by this method. Formerly it was customary to class all types of cardiac irregularity together, or at the

most to distinguish between "intermittence" and so-called "delirium cordis." To-day our knowledge of arrhythmia of the heart forms one of the most complete chapters of clinical medicine. We are largely indebted to electrocardiography for this knowledge. We now know that there are a number of different causes of disorderly heart action, and that they have widely different effects upon the circulation and upon the life-histories of the patients in whom they occur. We have learnt that the response of a heart, in which the chamber contractions are disorderly, to therapeutic agents is largely controlled by the nature of the disorder which is present. It is no longer sufficient to speak of this or that heart action as irregular; we must know the form of the irregularity, the part which each heart chamber plays in it, and its site of origin. This information is supplied by the galvanometer.

So-called "Intermittence" of the Pulse.

In many patients in whom the radial pulse and heart contract with perfect uniformity for long periods an occasional and isolated disturbance is noticed. The pulse is said to "intermit"—it loses one of the serial beats at intervals. The pause, which interrupts the otherwise perfectly regular pulse, is due to one of three causes:

1. *Whole Heart Silences.*—The pause may be due to a rare phenomenon, the complete loss of a whole heart-beat. During the pause the recorded line runs straight (Fig. 15 *a*); no trace of either auricular or ventricular contraction is visible during it. On account of the rarity of the condition, its prognostic significance is at present imperfectly understood. The irregularity is usually vagal in origin.

2. *Dropped Beats.*—The pause contains no ventricular contraction, but an auricular summit *P* is seen at the expected point (Fig. 15 *b*). When I say expected point, I mean that the auricular contraction falls at an equal distance between the preceding and succeeding contractions of the same chamber. The auricular rhythm is undisturbed, but a single response of the ventricle is lost.

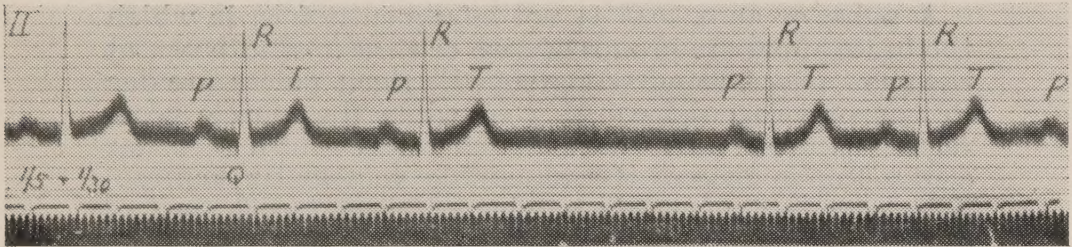
This form of heart irregularity is not infrequent, and is especially common in patients who are under the influence of drugs of the digitalis series. It also occurs in acute and chronic rheumatic infections, in pneumonia and other conditions. It is due to a deficiency in the functions of the auriculo-ventricular bundle (heart-block), and is in reality an exaggeration of a condition previously described—namely, prolongation of the *P-R* interval. Its significance is the same, and has been discussed in a previous article. It is a grave sign.

3. *Premature and Weak Contractions.*—The pause may be occupied by a premature and abnormal contraction of the ventricle.* The premature beat is recognized by its strange shape, and by its falling at a point earlier than might be anticipated. It prevents the response of the

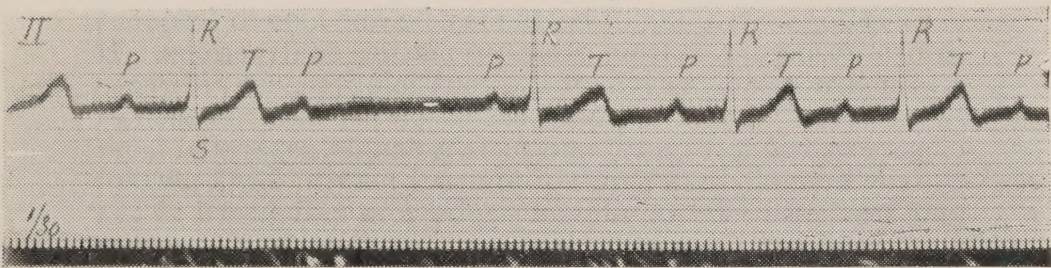
* It may also be occupied by other forms of premature beat, which for the sake of simplicity I shall not consider.

ventricle to the succeeding auricular contraction; and this auricular contraction usually falls with the abnormal ventricular beat (Fig. 15c). The auricular rhythm is undisturbed, and, after the pause, the ventricle again responds to the succeeding beats of the auricle.

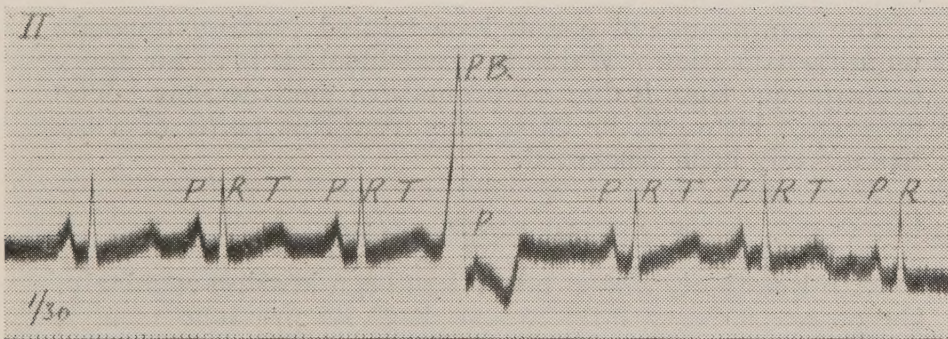
Figs. 15a, b, and c. Three electro-cardiograms, showing the manners in which intermittence of the pulse may arise.



a. A whole heart-beat, including auricular and ventricular contraction, has fallen out.



b. A ventricular contraction is missing. The auricular contraction is seen by itself and at approximately equal distances from adjacent auricular contractions. Thus the auricular rhythm is undisturbed, while, for one cycle, the ventricle fails to respond. The condition is one of partial heart-block.



c. The regular action of the heart (*P*, *R*, and *T*) is disturbed by the appearance of a premature ventricular contraction (*P.B.*). This contraction is represented by an electric curve of anomalous form, because it has started in the right and basal portions of the ventricular muscle, and not on both sides simultaneously, as is usual. The auricular rhythm is again undisturbed; there is no response to the auricular contraction, which falls with the premature beat, but response to succeeding auricular contractions is regular. The premature beat was weak and failed to reach the pulse.

It is often possible, from the form of abnormal beat, to identify the region of the ventricle from which it arises. It may be stated that it comes from the right or basal portions of the ventricle, or from the left or apical portions. The illustration (Fig. 15c) is of a beat which has arisen near the right and basal portion of the ventricle.*

* This conclusion is based upon experimental observations.

This form of irregularity is extremely common; most adult men of sedentary occupation exhibit it from time to time. It is a disturbance of little consequence. The importance of recognizing it lies chiefly in its possible confusion with the other forms of irregularity.

Coupled and Tripled Beats.

A pulse or apex beat is not infrequently felt, in which the beats appear in groups of two or three. The beats at the apex may be similarly grouped. Such pulses are due to one of two chief causes. If, while the auricle beats regularly, a response of the ventricle to each third auricular contraction is missed, the remaining ventricular contractions necessarily occur in couples. If each fourth beat of the ventricle is missed, the remaining beats occur in groups of three (Fig. 17). Coupled or tripled beating of this kind is the result of heart-block.

Coupling or tripling of beats may be due also to frequent intermittences, resulting from premature contractions. If a premature contraction of the ventricle replaces alternate heart cycles, then a normal beat and a premature beat fall closely together (Fig. 16) and form a couple, separated from the next couple by a pause of unusual length. Both normal and premature beats may often be felt and heard at the apex beat, but the premature (or second) beat of the couple may fail to affect the pulse. If the premature beat appears at the wrist the pulse beats are coupled. If it does not, the pulse-rate is half that found at the apex beat. Tripling is produced at the apex when a premature beat replaces each third normal cycle.

The significance of coupled or tripled beating depends upon its causation. If due to heart-block, it is of far more consequence than if due to premature contractions. The difference between the two forms from this point of view has already been discussed.

Halved Pulse-rate.

If in a patient, whose heart has been beating regularly, the pulse suddenly falls to one half its previous rate, it will be evident from the previous paragraph that the disturbance may be due to the occurrence of premature beats. If such be the cause, the electro-cardiogram will show the weak ventricular contractions. Often they may be discovered by ordinary clinical methods; but not infrequently, when the beats are exceptionally weak, and especially if the heart sounds are indistinct, they cannot be discovered in this manner. *However weak they may be they are always fully displayed by the galvanometer* (Fig. 16).

If the pulse-rate falls to half its original rate, the ventricular-rate may also fall to the same extent. In such a case the electro-cardiographic examination usually discovers two auricular contractions for each ventricular beat. Alternate auricular contractions have alone

awakened ventricular response. Halving of ventricular rate, produced in this way, is one of the types of bradycardia, two of which were described in a previous article.

Gross Irregularity of the Heart : Auricular Fibrillation.

There are many forms of heart irregularity other than those which I have so far described. It would occupy too great a space were I to attempt their description. I shall consequently confine myself to one further illustration.

In most patients who suffer from heart disease and in whom the pulse is irregular the pulse irregularity is of a gross type. In the examples of disordered action previously described the derangement is of relatively simple form, consisting of "intermittences," halving of rate, or groupings of beats which are repeated from minute to minute. But the heart's action may be so disorderly that the confusion is extreme, so that few of its cycles appear to be of the same length and the beats or pulsations are of varying strength. Such an irregularity may be due on

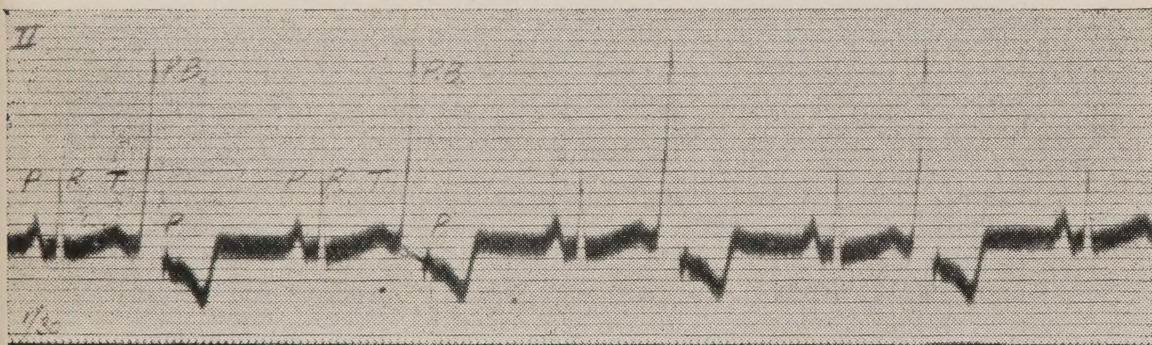


Fig. 16.—Electro-cardiogram showing one form of coupling of the heart beats. Each normal cycle (*P*, *R*, and *T*) is closely followed by a premature ventricular contraction (*P*, *B*), which coincides with an auricular beat. These abnormal beats have arisen in the right and basal portions of the ventricle (see Fig. 15 *c*). The premature beats failed to reach the pulse, the rate of which was 51 per minute. The auricular or true heart rate was 101.

rare occasions to irregular generation of the impulses at the normal site, and the whole heart is then involved in the same irregularity (Fig. 18). Such an irregularity is termed a sinus arrhythmia,* and is of no serious prognostic moment. It may also be due to a complex admixture of premature and normal beats, but this form of disordered action is also rare. In 60 to 70 per cent. of all failing hearts irregularity is the result of a remarkable phenomenon which I described in this JOURNAL three years ago, namely, fibrillation of the auricles. Auricular fibrillation is a condition in which the co-ordinate contraction of the upper chambers is entirely lost; the muscle fibres no longer move together and perform the act of systole, but the walls of the chambers stand in a position of diastole, while fine flickering movements are visible all over their surfaces.† The muscle

* Sinus irregularities also include the respiratory irregularities of children, where there is a waxing and waning of rate with each act of breathing.

† Our knowledge of these appearances has resulted from experiment.

mass seems to be subdivided into a number of small foci, each of which is contracting independently of the surrounding tissue. The active emptying of the auricles has ceased; they remain always full of blood. That is the mechanical effect of fibrillation; but there is a further and far more important effect. As soon as the co-ordinate contraction is replaced by fibrillation, so soon are the slow and rhythmic impulses which normally stimulate the ventricle lost, and they are replaced by a large number of haphazard impulses which issue from the auricular turmoil. The result is a rapid ventricular action of an extremely gross type.

The importance of fully understanding the mechanism of this pathological condition and appreciating its effects upon the circulation can scarcely be over-emphasized. In rheumatic heart disease it is one, if not the most serious, event in the history of the affection. As a general rule, once it appears it remains until death.* The rapid ventricular action which it engenders is immediately felt, and is often the cause of the initial breakdown; for a weakened heart muscle cannot maintain an unduly accelerated rate. Moreover, as a large number of the beats are weak and fail to reach the pulse, a great deal of the excessive work is wasted. The rapid and turbulent action is speedily followed by venous engorgement, and signs of pulmonary and abdominal stasis may soon appear as an immediate result.† Thus the irregularity is the *cause* of serious circulatory embarrassment, and is not, as was formerly taught, the *result* of such embarrassment. That such is the case is known, for the irregularity appears first; it serves as a warning of future events. Moreover, the circulatory failure is not always immediate; when the heart muscle is stronger it may not show signs of failure until months or years after the onset of the disturbance.

The recognition of the disorder when it is seen—and it is frequently seen by all who practise medicine—is of consequence from several points of view. When, as is so often the case, it develops in a case of mitral stenosis, a murmur limited to presystole is no longer audible, for this murmur is dependent upon co-ordinate contraction of the auricle. So it often happens that patients who have exhibited either no diastolic murmur, or only an early diastolic murmur at the apex during life,‡ are found to have mitral constriction after death.

But its recognition is of chief importance on account of the indications it gives for treatment. These are the cases in which digitalis may be looked to to give its conspicuous reaction. Administered in suitable doses, a great reduc-

* In a limited percentage of the cases it occurs in paroxysms, giving rise to a type of paroxysmal tachycardia, which is characterized by periods of gross pulse irregularity.

† The diastolic position of the auricles and consequent stagnation of blood in them might be supposed to predispose to infarction of the lungs; but so far I have been unable to find clear evidence of it. It may be that clots formed in the auricles while fibrillation is present are less readily detached.

‡ Such patients are not infrequently mistaken for aortic cases.

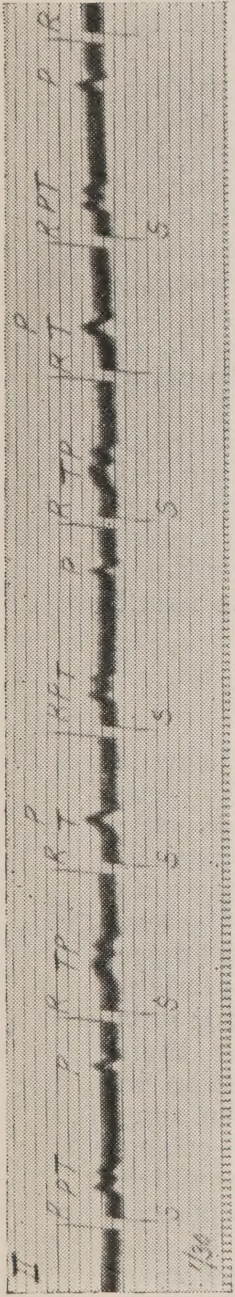


Fig. 17.—Electro-cardiogram showing one form of triple heart beats. All the ventricular beats (*R*, *S*, and *T*) are preceded by auricular beats (*P*); but there is a failure of the response to each fourth beats proceeds it gradually widens—that is to say, a gradually increasing difficulty in conduction occurs, until finally response fails at the end of each group.

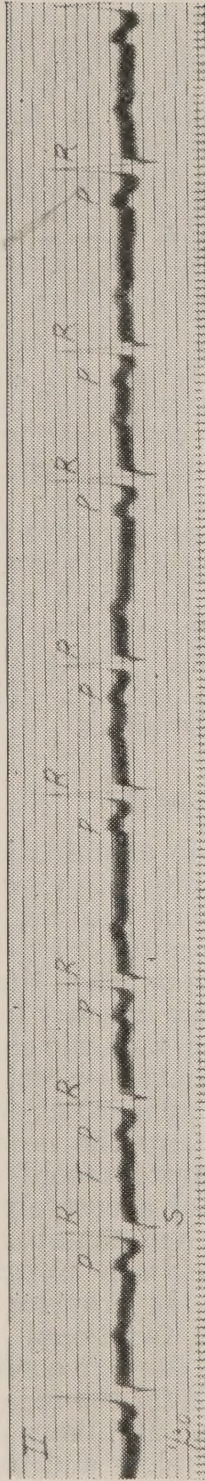


Fig. 18.—An electro-cardiogram from a patient who exhibited gross irregularity of the heart. It shows that the irregularity is of sinus origin—that is to say, the heart beats are *generated* irregularly. All the heart chambers are affected in the same manner each ventricular beat (*R*, *T*) is preceded by an auricular summit (*P*).

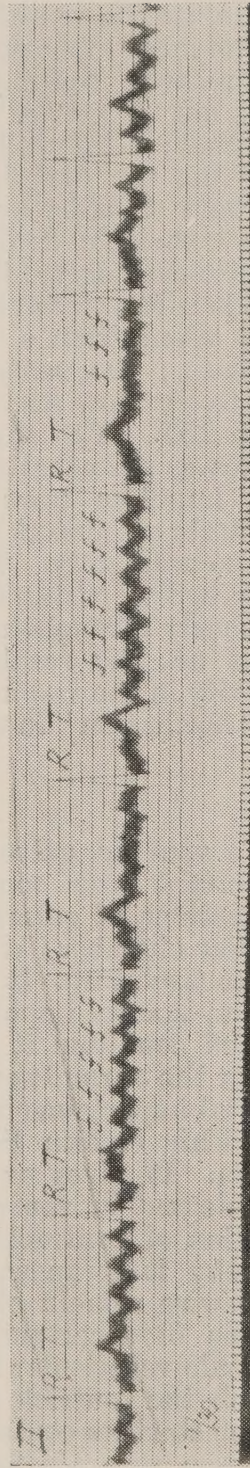


Fig. 19.—An electro-cardiogram taken from a case of mitral stenosis; the heart contracted in a grossly irregular fashion. The curve shows that the irregularity was due to auricular fibrillation. The ventricular beats are of the usual form (*R* and *T*); the impulses have consequently come down from a point above the ventricle. The whole curve shows continuous oscillations of large amplitude (the conspicuousness of the oscillations is an indication of auricular hypertrophy), oscillations which, as I have shown, result from the fibrillation of the auricles. There are no *P* summits, representing co-ordinate auricular contraction.

tion of heart rate and a rapid improvement of the circulatory conditions may be anticipated in a large number of the cases, especially in young subjects. The fibrillation is not abolished, but a check is placed, and may be maintained, upon the number of impulses which reach and stimulate the ventricle. In such cases digitalis brings one of the most successful changes which modern therapeutics can record. Not only does it bring the moribund back to life, but it staves off disaster in those in whom the approach of failure is threatened.

While the disorder may be recognized in a large percentage of cases by ordinary clinical means, its certain and invariable demonstration can only be accomplished electro-cardiographically. The type of curve which it yields is illustrated by the last figure (Fig. 19). The curve was taken from a patient already under the action of digitalis; the ventricular action (R, T) is consequently relatively slow (the actual rate is 70 per minute; it had been 150). The shape of the ventricular curves (R, T) indicates the usual spread of the ventricular contraction, the impulses have come from the auricle. True P summits are absent, for the auricles are no longer contracting co-ordinately. The P summits are replaced by a series of irregular oscillations (f, f) which may be traced continuously throughout the whole curve. These little oscillations are the result of the perpetual and tumultuous activity in the walls of the auricles. They are the result of "fibrillation" in these chambers.

SUMMARY.

To sum up, galvanometric examination of the heart is important from many points of view. It may give indications of enlargement of the walls of one or other cardiac chamber; it may accurately locate small lesions in the musculature. It informs us when the heart beat starts at the normal impulse centre or away from it; in the last named condition it tells us that the rhythm is no longer under the normal nervous control—a fact which is of fundamental importance in the management of our case; it tells us within certain limits where the new beats have their origin. It gives us a separate record of contraction in auricle and in ventricle, and accurately defines the time relation of contraction in one chamber and the other; thereby it frequently elucidates physical signs which otherwise remain obscure. It provides us with a perfect means of ascertaining the functional efficiency of the auriculo-ventricular bundle, the sole conducting tract upon which the ventricle depends for the reception of impulses which start its contractions. It allows us to differentiate between separate forms of slow and rapid heart action, which are of totally different significance. It provides us with an analysis of every form of cardiac irregularity, an analysis which is unrivalled in its precision by any other method. While the information derived from it relates essentially to the condition of the muscle, the method is

often helpful in the diagnosis of lesions of the valves. It brings us into nearer contact with the functions of the heart muscle than does any other clinical method ; it is a precise means of studying the heart as a living and moving organ.

The information obtained by electro-cardiography is not, as commonly thought, of purely scientific interest in the analysis of disordered heart action. It has a great and growing value in the practical management of patients. There are few heart cases in which our knowledge is not added to by its employment, and in a steadily increasing percentage facts which are essential if sound prognosis and treatment are to be attempted are elicited. The time is at hand, if it has not already come, when an examination of the heart is incomplete if this new method is neglected.

